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Continuous Discharge Line Source for the Extreme Ultraviolet

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A continuous gaseous discharge source suitable for use between 100 Å and 1000 Å is described. The source is stable, produces little or no electromagnetic interference, and is rich in high intensity lines throughout the extreme uv. The operating characteristics of this source and its spectral output with various gases are presented.

Introduction

Because of the growing importance of the study of extreme uv radiation (xuv),[1-5] there is considerable interest in the development of high intensity radiation sources for this spectral range. A variety of sources have been proposed for these wavelengths,[6] most of which are subject to some limitations. This is especially true for sources intended for use below 500 Å. To produce radiation at these wavelengths, one usually must resort to pulsed discharge sources or magnetically constrained plasma sources, such as the duoplasmatron. A pulsed discharge source typically produces intense radio frequency background radiation. Experience has shown that to reduce this noise to tolerable levels, the entire source and all its associated circuitry must be placed inside a grounded metal cage. This obviously introduces mechanical limitations on its use.

The duoplasmatron source is mechanically rather complex and somewhat difficult to operate. For instance, the cathode must be reactivated each time it is exposed to air, a time-consuming process limiting the versatility of the device. A second drawback is that the entrance slit of the monochromator must be removed and replaced by a special source-slit combination. This operation entails a complex mounting and aligning problem for many monochromators.

An important factor to be considered in the design of a source suitable for use in any xuv calibration system is that the efficiencies of normal incidence monochromators decrease rapidly below 500 Å. Grazing incidence mounts can be employed at these wavelengths, but these typically employ rather complex movements of either the source or the detector, which introduces additional mechanical limitations. Monochromators such as the Seya-Namioka have the tremendous advantage of fixed entrance and exit slits combined with extremely simple scanning mechanisms. It is highly desirable, therefore, that the output of any xuv source be sufficiently intense that it can be used with this type of monochromator.

These considerations have led us to develop a high intensity continuous discharge source suitable for use at wavelengths below 500 Å. We note that similar motivations have prompted at least one other experimental group to develop an xuv source with many of the same characteristics as the one we describe here.[7]

Description of the Source

The source we have developed is similar in concept to the source described by Newburgh *et al.*,[8,9] but it is substantially different from that source in a number of important respects. An important feature of both of these sources is that the discharge is confined in such a manner that the negative glow of the gas discharge can be viewed directly. Most of the ionic line emissions are produced in this region and can, therefore, be observed with little or no absorption by intervening neutral gas in the positive column.

A schematic of the source is shown in Fig. 1. Both anode and cathode are constructed to allow for water cooling. The cathode is a hollow tube made of elkonite, a copper–tungsten alloy that has the advantages of a low sputtering rate and high heat conductivity and is easy to machine. The cathode has a 1-cm i.d. and a 2.5-cm o.d. The cathode tip, also of elkonite, is removable, allowing for experimentation with various types of geometries. The cathode is protected from erosion by ion bombardment by a thin quartz tube. The cathode is welded to a brass flange 8 cm in diam-

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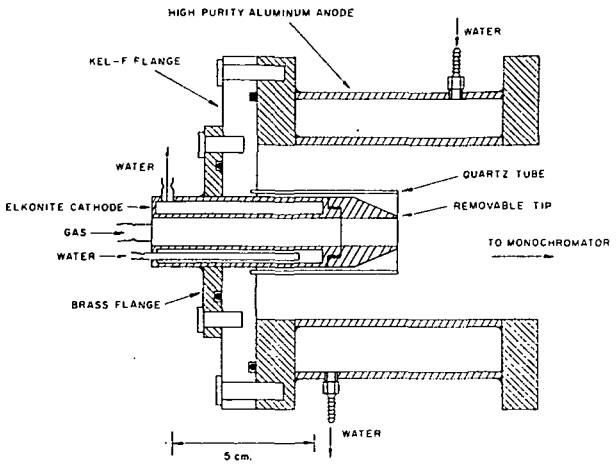

Fig. 1. Schematic diagram of the source.

eter, which is, in turn, sealed with an O-ring to a 12-cm diam Kel-F flange. This flange electrically isolates the cathode from the anode. The anode is a double-walled cylinder constructed of high purity 1100 aluminum alloy. In operation the source is buffered from the monochromator through a 5-cm long differential pumping stage.

The source is energized by a conventionally stabilized dc power supply run in series with an air-cooled ballast resistor bank of approximately 3-kΩ resistance. The discharge current can be varied between 50 mA and 800 mA at voltages between 500 V and 2000 V. To strike the discharge, up to 5000 V are required. For the highest discharge currents, water flow at a rate of 3 liters/min for the anode and of 1 liter/min for the cathode is found to provide adequate cooling.

We typically employ commercial grade gases (on the order of 0.01% impurities) with the source. The gas flow to the source is controlled by a precision needle valve assembly. Since the pressure within the source is nonuniform, it is somewhat meaningless to speak of a single source pressure. Nonetheless, the characteristics of the discharge are pressure dependent. Hence, it is necessary to specify this parameter in some manner. We chose to do this by specifying the pressure at a point in the differential pumping stage quite near the cathode tip. In normal operation the pressure at this point is between 10 Torr and 0.06 Torr. The corresponding pressure range measured at the inlet to the cathode is 50–0.2 Torr.

Spectroscopic Instrumentation

The source is mounted on a 1-m Seya-Namioka monochromator evacuated by a high speed diffusion pump. Under typical operating conditions the pressure in the monochromator varies between 5×10^{-5} Torr and 5×10^{-3} Torr, with the entrance slit 400 μ wide. The grating employed is a 1200 line/mm platinized concave grating blazed at 400 Å with a ruled area of 15 cm^2. The plate factor is approximately 6 Å/mm in the first order.

The radiation emerging from the exit slit of the monochromator is recorded by means of a channel electron multiplier (CEM) whose operating characteristics have been described elsewhere.[10] This detector is housed in an independently pumped chamber in

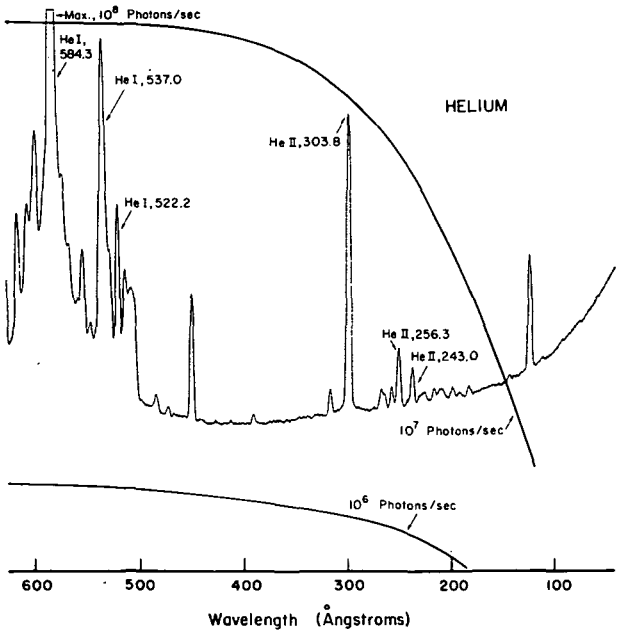

Fig. 2. Helium spectrum from the source. Operating conditions: entrance and exit slits 400 μ and 100 μ wide, respectively, discharge current 500 mA, pressure 1-mm Torr, scanning rate 50 Å/min, channel electron multiplier detector.

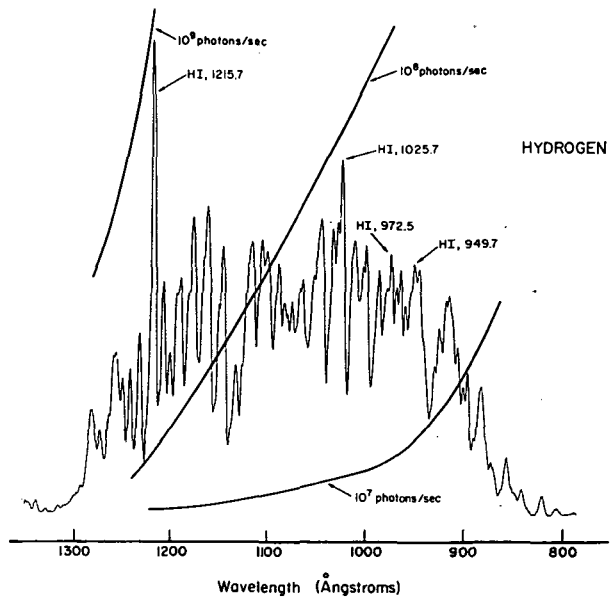

Fig. 3. Hydrogen spectrum from the source. Operating conditions: entrance and exit slits 400 μ and 100 μ wide, respectively, discharge current 500 mA, pressure 0.7 Torr, scanning rate 50 Å/min, channel electron multiplier detector.

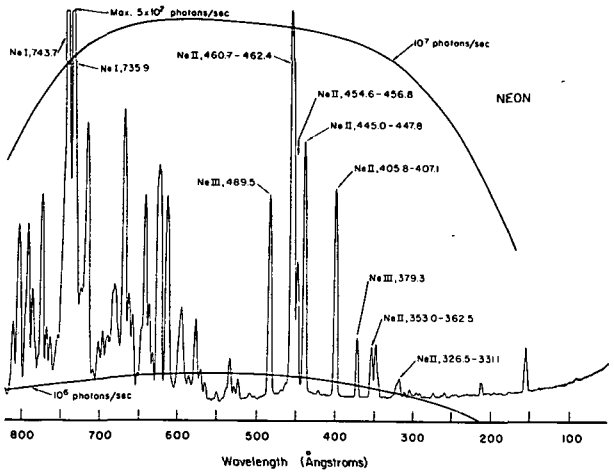

Fig. 4. Neon spectrum from the source. Operating conditions: entrance and exit slits 400 μ and 100 μ wide, respectively, discharge current 500 mA, pressure 0.8 Torr, scanning rate 50 Å/min, channel electron multiplier detector.

which the pressure is always kept below 10^{-5} Torr. The quantum efficiency of the channel electron multiplier is measured to an accuracy of $\pm 30\%$ by means of the gold photodiode technique described by Samson.[6] The output pulses of the CEM are fed to an electronic system consisting of a preamplifier, an amplifier–discriminator, and a linear ratemeter. The output of the ratemeter is fed to a conventional strip chart recorder.

Results and Discussion

Figures 2 through 5 show the output of the source with various gases. Because these spectra are recorded at relatively high speed (50 Å/min), a small distortion in the line widths and peak intensities is introduced. Intensity contours showing the photon flux at the exit slit are indicated. These contours take into account the measured wavelength sensitivity of the CEM, the distortion due to the scanning rate, and the position of the CEM with respect to the exit slit. The absolute intensity of these contour lines is known only to within $\pm 30\%$, the uncertainty in the CEM calibration.

Since no effort is made to purify the gases entering the source, many impurity lines are present in the spectra, most notably those of hydrogen, oxygen, and nitrogen. A number of unidentified lines also appear between 300 Å and 130 Å in the spectra of helium, argon, and neon. Various tests performed on these lines have shown that they are not due to discontinuities in the detector response nor to geometrical scattering processes. Tests by filter photometry show that the lines do, in fact, fall in the wavelength range from 100 Å to 300 Å. Since these lines appear to be characteristic of the gas and appear under all possible conditions of excitation, they probably originate in the reaction of the gas with some unknown impurity. At wavelengths longer than approximately 500 Å, second-order lines appear in the spectra. These are of lower intensities than the first-order lines because of the grating blaze

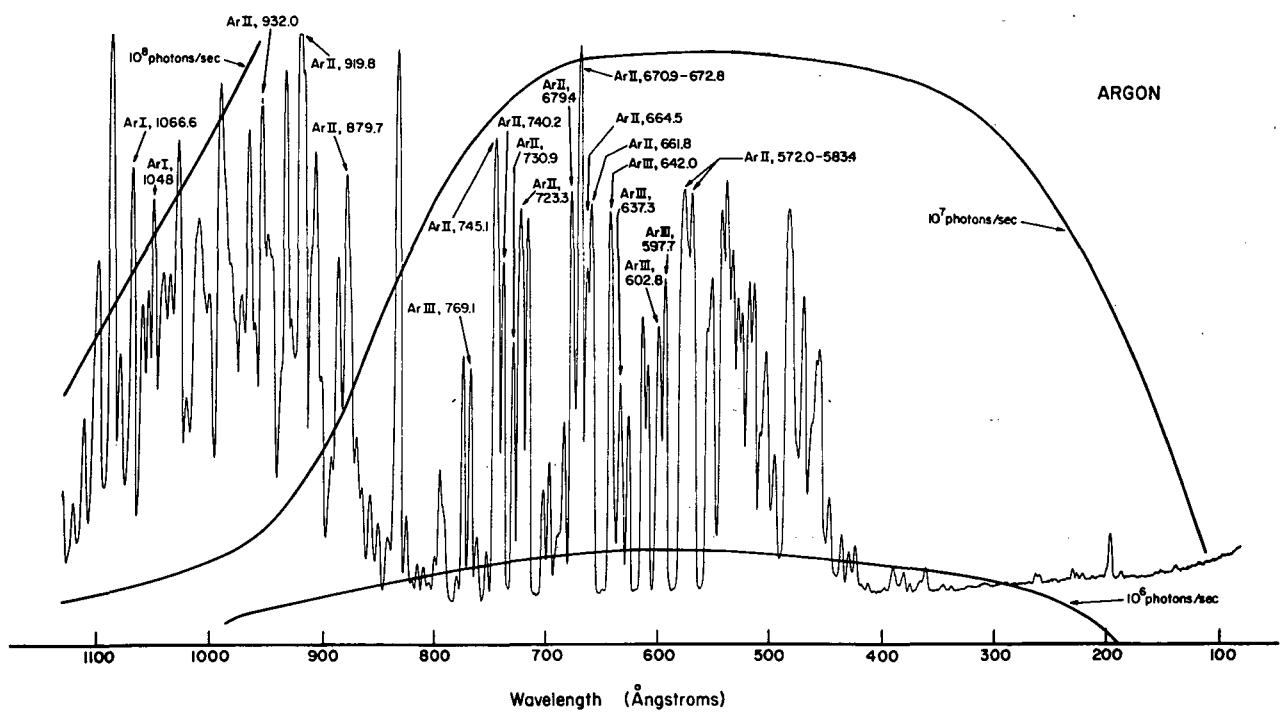

Fig. 5. Argon spectrum from the source. Operating conditions: entrance and exit slits 400 μ and 100 μ wide, respectively, discharge current 500 mA, pressure 0.7 Torr, scanning rate 50 Å/min, channel electron multiplier detector.

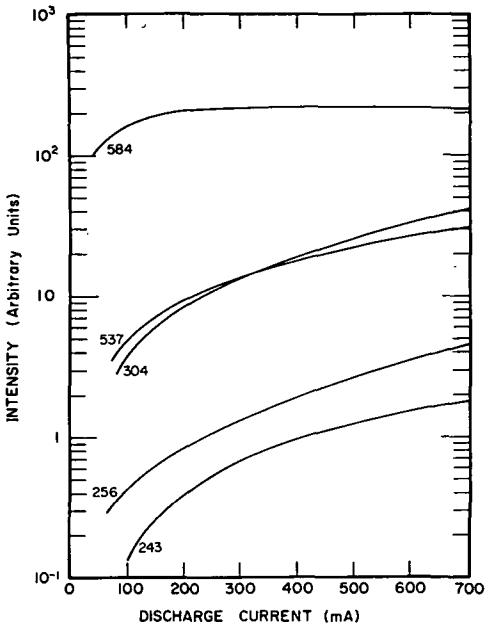

Fig. 6. Relative intensity of helium lines as a function of discharge current for a fixed pressure of 0.7 Torr.

and are easily eliminated by the use of xuv bandpass filters such as thin films of tin or indium.[10]

The radiation emitted by this source is seen to be rich in lines from neutral atoms as well as from singly and doubly ionized atoms. In this respect the source differs from typical capillary glow discharge devices and is instead more like the duoplasmatron source. In fact, a comparison with typical spectra obtained with a duoplasmatron shows that the two sources excite much the same lines. A direct comparison of the intensities of the two sources is unfortunately somewhat difficult to make because of different operating conditions among experimenters.

The output of the source is quite stable. We have made continuous runs for periods as long as 6 h and have observed no intensity changes larger than ±1%. The source also appears to be quite durable. In over 100 h of intermittent operation, we can see no indications of degradation in performance.

Parametric Studies of the Discharge

The intensity of the xuv radiation emitted by the source is found to be dependent upon both the pressure and the current in the discharge, and a number of helium lines were studied to evaluate the effects of changes in these parameters. The lines selected for this study were the He I lines at 584.3 Å and 537 Å and the He II lines at 303.8 Å and 256 Å. The results obtained are found to be generally similar to results obtained for other gases, so that the conclusions reached for helium are useful for deciding the optimum operating values for any gas.

In Fig. 6 we show the dependence of line intensity with discharge current. All line intensities are seen to increase with discharge current, although the 584-Å line quickly saturates. The ratios of 584-Å to 537-Å radiation and 304-Å to 256-Å radiation decrease with increasing discharge current toward a common value of approximately 5.

The increase in electron density and plasma temperature associated with an increase in the discharge current results in an increase of the population of excited states. This suggests that, as the discharge current is increased, a resonance line such as He 584 Å or He 304 Å will increase in intensity, saturate, then decrease slowly as an increasing fraction of the available energy is used in exciting other states. The increase in line intensities and decrease in line ratios [I (584 Å)/I (537 Å), I (304 Å)/I (256 Å), I (584 Å)/I (304 Å)] with increasing discharge currents and the slow decrease of the He I, 584-Å line at high discharge currents can all be reasonably attributed to this effect.

The behavior of the source with respect to changes in pressure is also instructive. We have plotted these data in Fig. 7. At low pressures the intensities of all lines are seen to increase with increasing pressure. The 584-Å line increases almost exponentially to a maximum value and thereafter decreases very slowly with further increase in pressure. The 537-Å line reaches a maximum at a much lower pressure and thereafter decreases slowly. Like the 584-Å line, it is not very pressure sensitive over most of the pressure range studied. The decrease of the intensity of the 304-Å line after attaining its peak value is much more precipitous. The 256-Å He II line behaves in a manner similar to the 304-Å line. It is clear that the ionic lines are extremely sensitive to pressure and that, to maximize their intensity, one must operate the source with low gas pressure and with high discharge currents.

The behavior of the line intensities as pressure is varied and is probably due to three distinct processes:

1. *Self-absorption.* This effect will become more important at higher pressures and is probably responsible for the slow decline in intensity of the 584-Å line at higher pressures.

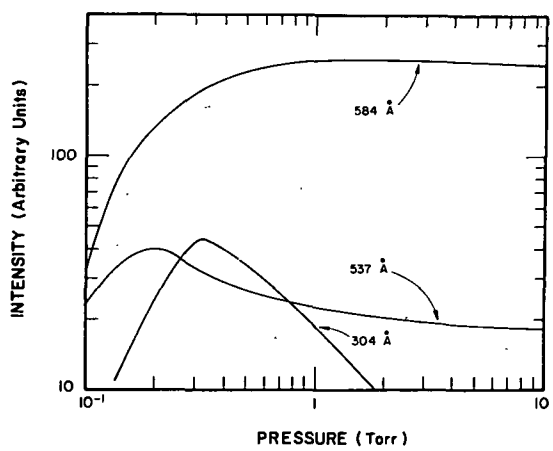

Fig. 7. Relative intensity of helium lines as a function of pressure for a fixed discharge current of 500 mA.

(2) *The decrease in the population of ionized constituents with increasing pressure.* This effect is predicted by the Saha equation and is probably primarily responsible for the rapid decrease of intensity of the 304-Å line.

(3) *Collisional de-excitation.* This phenomenon probably depopulates the excited 3^1P state through the process $He^* + He \rightarrow He_2^+ + e$ and produces the moderate decline in intensity of the 537-Å line with increasing pressure.

On the supposition that the shape of the electric field in the vicinity of the cathode would have a considerable effect on the source strength, a study was made of the effect of various tip geometries on the source intensity. This hypothesis appeared to be supported by our observation that the effect of particle bombardment on the quartz protective tube seemed to be limited to the tip of the cathode. To investigate this dependence, three types of cathode tip geometry were employed—one with the cathode cylinder wall beveled to a knife edge at the inside of the wall, one with the tip beveled to a knife edge at the outside of the wall, and the third with a simple thin-walled cylindrical geometry. The slight variations in the intensities (never exceeding 10%) are not significant enough to be clearly attributable to changes in the tip geometry. We also find that the source strength is generally insensitive to the length of the cathode.

Conclusions

The device described here possesses a number of advantages as a source of xuv radiation. It is simple and inexpensive to construct. It is easy to operate and is not a source of spurious electromagnetic radiation. The source output is very stable. A wide range of both ionic and neutral emission lines is produced with inexpensive and commonly available gases. The output spectrum is sufficiently intense that the source can be used with a Seya-Namioka monochromator at wavelengths as low as 160 Å.

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